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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
APPLICATION FOR U.S. LETTERS PATENT

Title:

SINGLE POLARITY PROGRAMMING OF A PCRAM STRUCTURE

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SINGLE POLARITY PROGRAMMING OF A PCRAM STRUCTURE

FIELD OF THE INVENTION

[0001] The invention relates to the field of random access memory (RAM) devices formed using a resistance variable material, and in particular to a method and apparatus for writing a particular resistance state of a chalcogenide glass memory element.

BACKGROUND OF THE INVENTION

[0002] Recently, resistance variable memory elements, which include programmable conductor memory elements based on chalcogenide glasses, have been investigated for suitability as semi-volatile and non-volatile random access memory elements.

[0003] The mechanism by which the resistance of a chalcogenide glass memory element is changed is not fully understood. In one theory, the conductively-doped dielectric material undergoes a structural change at a certain applied voltage. It is surmised that a conductive dendrite or filament grows under influence of the applied voltage to extend between the electrodes, effectively interconnecting the two electrodes and setting the memory element to a low resistance state. The dendrite is thought to grow through the resistance variable material along a path of least resistance.

[0004] The low resistance state will remain intact for days or weeks after the voltage potentials are removed. Such materials can be returned to a high resistance state by applying a reverse voltage potential between the electrodes, the reverse potential having at least the same order of magnitude as was used to write the element to the low resistance state. Again, the highly resistive state is maintained once the voltage potential is removed. This way, such a device can function, for

example, as a resistance variable memory element having two resistance states, which can define two logic states.

[0005] As noted above, resistance variable materials of particular interest include chalcogenide glasses doped with a conductive substance that will disperse or migrate within the glass. A specific example is germanium-selenide glass ($\text{Ge}_x\text{Se}_{100-x}$), doped with silver (Ag). Another example is a germanium-selenide glass ($\text{Ge}_x\text{Se}_{100-x}$) which receives silver ions through an adjacent silver-selenide (Ag_2Se) layer.

[0006] Known memory elements based on silver-containing chalcogenide materials require that pulses of reverse polarity be applied to switch the memory element between the different resistance states. Since it is often inconvenient to supply a negative potential power source to a memory device, it would be desirable to have a resistance variable memory element which switches between resistance memory states using different levels of a positive voltage.

BRIEF SUMMARY OF THE INVENTION

[0007] In a first embodiment, the invention provides a resistance variable memory element in which a metal, e.g., silver, containing layer is formed between two chalcogenide glass layers, the memory element being switchable between two resistance states by application of write voltage pulses of different levels but of the same polarity.

[0008] The metal-containing layer may be a layer of silver-selenide formed between the two chalcogenide glass layers.

[0009] According to a second embodiment, the invention provides a memory element including a plurality of alternating layers of chalcogenide glass and metal containing layers, whereby the layers start with a first chalcogenide glass layer and end with a last chalcogenide glass layer, with the first chalcogenide glass layer contacting a first electrode and the last chalcogenide glass layer contacting a second electrode. The plurality of alternating layers of chalcogenide glass layers and metal

containing layers are stacked between two electrodes. The metal containing layers preferably include a silver-chalcogenide, such as silver-selenide. The memory element of the second embodiment is also switchable between two resistance states by application of write voltage pulses of different levels but of the same polarities.

[0010] These and other features and advantages of the invention will be better understood from the following detailed description, which is provided in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 illustrates a cross-sectional view of a simplified memory element and an accompanying read/write circuit in accordance with an exemplary embodiment of the present invention.

[0012] FIG. 2 illustrates a cross-sectional view of a simplified memory element in accordance with an alternative exemplary embodiment of the present invention.

[0013] FIG. 3 illustrates a cross-sectional view of a simplified memory element in accordance with another alternative exemplary embodiment of the present invention.

[0014] FIG. 4 illustrates a cross-sectional view of a simplified memory element in accordance with a further alternative exemplary embodiment of the present invention.

[0015] FIG. 5 is a graph illustrating write voltages and resistance states of the memory elements of the present invention.

[0016] FIG. 6 illustrates a processor-based system having a memory including memory elements in accordance with an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0017] In the following detailed description, reference is made to various specific embodiments of the invention. These embodiments are described with sufficient detail to enable those skilled in the art to practice the invention. It is to be understood that other embodiments may be employed, and that various structural, logical and electrical changes may be made without departing from the spirit or scope of the invention.

[0018] The term “substrate” used in the following description may include any supporting structure including but not limited to a semiconductor substrate or a non-semiconductor substrate. A semiconductor substrate should be understood to include silicon, silicon-on-insulator (SOI), silicon-on-sapphire (SOS), doped and undoped semiconductors, epitaxial layers of silicon supported by a base semiconductor foundation, and other semiconductor structures.

[0019] The term “silver” is intended to include not only elemental silver, but silver with other trace metals or in various alloyed combinations with other metals as known in the semiconductor industry, as long as such silver alloy is conductive, and as long as the physical and electrical properties of the silver remain unchanged.

[0020] The term “silver-selenide” is intended to include various species of silver-selenide, including some species which have a slight excess (+x) or deficit (-x) of silver, for instance, Ag_2Se , Ag_{2+x}Se , and Ag_{2-x}Se .

[0021] The term “chalcogenide glass” is intended to include glasses that contain an element from group VIA (or group 16) of the periodic table. Group VIA

elements, also referred to as chalcogens, include sulfur (S), selenium (Se), tellurium (Te), polonium (Po), and oxygen (O).

[0022] The invention will now be explained with reference to FIG. 1, which illustrates an exemplary embodiment of a resistance variable memory element 2 in accordance with the invention. FIG. 1 depicts a portion of an insulating layer 12 formed over a substrate 10, for example, a silicon substrate. It should be understood that the resistance variable memory element can be formed over a variety of substrate materials and not just semiconductor substrates such as silicon. For example, the insulating layer 12 may be formed over a plastic substrate.

[0023] The insulating layer 12 may be formed by any known deposition methods, such as sputtering by chemical vapor deposition (CVD), plasma enhanced CVD (PECVD) or physical vapor deposition (PVD). The insulating layer 12 may be formed of a conventional insulating oxide, such as silicon oxide (SiO_2), a silicon nitride (Si_3N_4), or a low dielectric constant material, among many others.

[0024] A first electrode 14 is next formed over the insulating layer 12, as also illustrated in FIG. 1. The first electrode 14 may include any conductive material, for example, tungsten, nickel, tantalum, aluminum, or platinum, among many others. A first dielectric layer 15 is next formed over the first electrode 14. The first dielectric layer 15 may include the same or different materials as those described above with reference to the insulating layer 12.

[0025] An opening extending to the first electrode 14 is formed in the first dielectric layer 15 by known methods in the art, for example, by a conventional patterning and etching process. A first chalcogenide glass layer 17 is next formed over the first dielectric layer 15, to fill in the opening.

[0026] According to a first exemplary embodiment of the invention, the first chalcogenide glass layer 17 is a germanium-selenide glass having a $\text{Ge}_x\text{Se}_{100-x}$ stoichiometry. The preferred stoichiometric range is between about $\text{Ge}_{18}\text{Se}_{82}$ to

about $\text{Ge}_{43}\text{Se}_{57}$ and is more preferably about $\text{Ge}_{40}\text{Se}_{60}$. The first chalcogenide glass layer 17 preferably has a thickness from about 100 Å to about 1000 Å and is more preferably about 150 Å.

[0027] The first chalcogenide glass layer acts as a glass backbone for allowing a conductive, metal-containing layer, such as a silver-selenide layer, to be directly deposited thereon. The use of a metal containing layer, such as a silver-selenide layer, in contact with the chalcogenide glass layer makes it unnecessary to provide a metal (silver) doped chalcogenide glass, which would require photodoping of the substrate with light radiation. It is possible, however, to also metal (silver) dope the chalcogenide glass layer, which is in contact with the silver-selenide layer, as an optional variant.

[0028] The formation of the first chalcogenide glass layer 17, having a stoichiometric composition in accordance with the invention, may be accomplished by any suitable method. For instance, evaporation, co-sputtering germanium and selenium in the appropriate ratios, sputtering using a germanium-selenide target having the desired stoichiometry, or chemical vapor deposition with stoichiometric amounts of GeH_4 and SeH_2 gases (or various compositions of these gases), which result in a germanium-selenide film of the desired stoichiometry are examples of methods which may be used to form the first chalcogenide glass layer 17.

[0029] A first metal containing layer 18, preferably silver-selenide, is deposited over the first chalcogenide glass layer 17. Any suitable metal containing layer may be used, including, for instance, silver-chalcogenide layers. Silver sulfide, silver oxide, and silver telluride are all suitable silver-chalcogenides that may be used in combination with any suitable chalcogenide glass layer. A variety of processes can be used to form the silver-selenide layer 18. For instance, physical vapor deposition techniques such as evaporative deposition and sputtering may be used. Other processes such as chemical vapor deposition, co-evaporation, or depositing a layer of selenium above a layer of silver to form silver-selenide can also be used.

[0030] The layers may be any suitable thickness. The thickness of the layers depend upon the desired electrical switching characteristics. The thickness of the layers is such that the metal containing layer is thicker than the first chalcogenide glass layer. The metal containing layer is also thicker than a second chalcogenide glass layer, described below. More preferably, the thicknesses of the layers are such that a ratio of the silver-selenide layer thickness to the first chalcogenide glass layer thickness is between about 5:1 and about 1:1. In other words, the thickness of the silver-selenide layer is between about 1 to about 5 times greater than the thickness of the first chalcogenide glass layer. Even more preferably, the ratio is between about 3.1:1 and about 2:1 silver-selenide layer thickness to first chalcogenide glass layer thickness.

[0031] A second chalcogenide glass layer 20 is formed over the first silver-selenide layer 18. The second chalcogenide glass layer allows deposition of silver above the silver-selenide layer since silver cannot be directly deposited on silver-selenide. Also, it is believed that the second chalcogenide glass layer may prevent or regulate migration of metal, such as silver, from an electrode into the element. Accordingly, although the exact mechanism by which the second chalcogenide glass layer may regulate or prevent metal migration is not clearly understood, the second chalcogenide glass layer may act as a silver diffusion control layer. The second chalcogenide glass layer may, but need not, have the same stoichiometric composition as the first chalcogenide glass layer, e.g., $\text{Ge}_x\text{Se}_{100-x}$. Thus, the second chalcogenide glass layer 20 may be of a different material, different stoichiometry, and/or more rigid than the first chalcogenide glass layer 17.

[0032] The thickness of the layers are such that the silver-selenide layer 18 thickness is greater than the thickness of the second chalcogenide glass layer 20. Preferably, a ratio of the silver-selenide layer thickness to the second chalcogenide glass layer thickness is between about 5:1 and about 1:1. More preferably, the ratio of the silver-selenide layer thickness to the thickness of the second chalcogenide glass layer is between about 3.3:1 and about 2:1 silver-selenide layer thickness to second

chalcogenide glass layer thickness. The second chalcogenide glass layer 20 preferably has a thickness between about 100 Å to about 1000 Å and is more preferably 150 Å.

[0033] The formation of the second chalcogenide glass layer 20 may be accomplished by any suitable method. For instance, chemical vapor deposition, evaporation, co-sputtering, or sputtering using a target having the desired stoichiometry, may be used.

[0034] A second conductive electrode material 22 is formed over the second chalcogenide glass layer 20. As with the first conductive electrode, the second conductive electrode material 22 may include any electrically conductive material, for example, tungsten, tantalum, titanium, or silver, among many others. Typically, the second conductive electrode material 22 includes silver. Thus, advantageously, the second chalcogenide glass layer 20 may be chosen to considerably slow or prevent migration of electrically conductive metals, such as silver, through the resistance variable memory element 2.

[0035] One or more additional dielectric layers may be formed over the second electrode 22 and the first dielectric layer 15 to isolate the resistance variable memory element 2 from other structure fabricated over the substrate 12. Conventional processing steps can then be carried out to electrically couple the second electrode 22 to various circuits of memory arrays.

[0036] A resistance variable memory element made of a PCRAM stack fabricated as described has been observed to switch to a low resistance state upon application of a first positive write pulse across the upper and lower electrodes, and to switch to a high resistance state upon application of a second higher positive write pulse across the electrodes. The pulses are applied by read/write circuit 24 as shown diagrammatically in Fig. 1. The first and second positive write pulses may have a pulse width of less than or equal to 8 nanoseconds. The Fig. 1 device switches to a low resistance state when the first write pulse has a magnitude of in the range of about

500 mV to about 1 V. The low resistance state is about 1 to 10K Ω , and thus can be obtained with a write pulse as low as about 500 mV. The device switches to a high resistance state when a second positive write pulse is applied having a magnitude of at least approximately 2.5 V, providing a high resistance state in the Megohm range. Pulse widths longer than 8 nanoseconds can be used, and with the appropriate potential, can exceed 1 microsecond. Thus, the resistance variable memory element of the present invention is switchable between two discrete resistance states, one lower and the other high, upon application of positive write voltage pulses.

[0037] Either resistance state can be read upon application of a positive voltage of less than 400 mV which will not erase the memory or cause a resistance change in the memory element. A destructive read is also possible, whereby a negative or positive potential could be used to read the device and concomitantly perturb the state of the memory cell which then needs to be refreshed to its original memory state.

[0038] In accordance with a variation of the first embodiment of the invention, one or more layers of a metal containing material, such as silver-selenide, may be deposited on the first chalcogenide glass layer 17. Any number of silver-selenide layers may be used. Thus, an optional second silver-selenide layer may be deposited on the first silver-selenide layer 18.

[0039] The thickness of the layers is such that the total thickness of the combined metal containing layers, e.g., silver-selenide layers, is greater than or equal to the thickness of the first chalcogenide glass layer. The total thickness of the combined metal containing layers is also greater than the thickness of the second chalcogenide glass layer. It is preferred that the total thickness of the combined metal containing layers is between about 1 to about 5 times greater than the thickness of the first chalcogenide glass layer and accordingly between about 1 to about 5 times greater than the thickness of the second chalcogenide glass layer. It is

even more preferred that the total thickness of the combined metal containing layers is between about 2 to about 3.3 times greater than the thicknesses of the first chalcogenide glass layer and the second chalcogenide glass layer.

[0040] In accordance, with yet another variation of the invention, the first chalcogenide glass layer may include one or more layers of a chalcogenide glass material, such as germanium-selenide. The second chalcogenide glass layer may also include one or more layers of a chalcogenide glass material. Any suitable number of layers may be used to include the first chalcogenide glass layer and/or the second chalcogenide glass layer. It is to be understood, however, that the total thickness of the metal containing layer(s) should be thicker than the total thickness of the one or more layers of chalcogenide glass and additionally the total thickness of the metal containing layer(s) should be thicker than the total thickness of the one or more layers of the second chalcogenide glass layer. Preferably a ratio of the total thickness of the metal containing layer(s) to the total thickness of the one or more layers of chalcogenide glass is between about 5:1 and about 1:1. Also, a ratio of the total thickness of the metal containing layer(s) to the total thickness of the one or more layers of the second chalcogenide glass preferably is between about 5:1 and about 1:1. It is even more preferred that the total thickness of the metal containing layer(s) is between about 2 to about 3.3 times greater than the total thicknesses of the combined one or more layers of chalcogenide glass and the total thickness of the combined one or more layers of the second chalcogenide glass.

[0041] In accordance with yet another variant of the invention, one or more of the chalcogenide glass layers may also be doped with a dopant, such as a metal, preferably silver.

[0042] Referring now to FIG. 2, a second exemplary embodiment of the present invention is illustrated in which the stack of layers formed between the first and second electrodes may include alternating layers of chalcogenide glass and a metal containing layer such as a silver-selenide layer. As shown in FIG. 2, memory

element 30 includes a first chalcogenide glass layer 17 stacked atop a first electrode 14. A first silver-selenide layer 18 is stacked atop the first chalcogenide glass layer 17, a second chalcogenide glass layer 117 is stacked atop the first silver-selenide layer 18, a second silver-selenide layer 118 is stacked atop the second chalcogenide glass layer 117, and a third chalcogenide glass layer 217 is stacked atop the second silver-selenide layer 118. The second conductive electrode 22 is formed over the fourth chalcogenide glass layer.

[0043] In accordance with the second embodiment, the stack includes at least two metal containing layers and at least three chalcogenide glass layers. However, it is to be understood that the stack may include numerous alternating layers of chalcogenide glass and silver-selenide, so long as the alternating layers start with a first chalcogenide glass layer and end with a last chalcogenide glass layer, with the first chalcogenide glass layer contacting a first electrode and the last chalcogenide glass layer contacting a second electrode. The thickness and ratios of the alternating layers of silver-selenide and chalcogenide glass are the same as described above, in that the silver-selenide layers are preferably thicker than connecting chalcogenide glass layers, in a ratio of between about 5:1 and about 1:1 silver-selenide layer to connected chalcogenide glass layer, and more preferably between about 3.3:1 and 2:1 silver-selenide layer to connected chalcogenide glass layer.

[0044] In a variation of the second embodiment, one or more layers of a metal containing material, such as silver-selenide may be deposited between the chalcogenide glass layers. Any number of silver-selenide layers may be used. In an additional variation, one or more Ag layer(s) can be included alternately with the silver-selenide layers.

[0045] In accordance, with yet another variation of the invention, each of the chalcogenide glass layers may include one or more thinner layers of a chalcogenide glass material, such as germanium-selenide. Any suitable number of layers may be used to include the chalcogenide glass layers.

[0046] In yet another variation of the second embodiment of the invention, one or more of the chalcogenide glass layers may also be doped with a dopant such as a metal, preferably including silver.

[0047] Referring to Fig. 3, a simplified structure of a third exemplary embodiment of a memory cell according to the present invention is shown in which a silver selenide layer 219 is formed on an electrode 214. Over the silver selenide a layer of $\text{Ge}_{40}\text{Se}_{60}$ glass is disposed, on which an upper electrode 222 containing silver is provided. According to an alternative version, silver selenide layer 218 is composed of Ag_{2+x}Se , in which case upper electrode 222 need not contain silver due to the extra silver in layer 218.

[0048] Referring to Fig. 4, a fourth exemplary embodiment of the present invention is shown in which a silver-doped glass layer 317 is sandwiched between two electrodes 314 and 322. The silver-doped glass composition $\text{Ge}_x\text{Se}_{100-x}$ needs to be in a stoichiometric range from $\text{Ge}_{18}\text{Se}_{82}$ to $\text{Ge}_{43}\text{Se}_{57}$, and preferably $\text{Ge}_{25}\text{Se}_{75}$ doped with silver either fully or within 1-10% of the maximum amount of silver allowed to keep the material amorphous. The preferred silver-doped glass compositions are described in commonly-assigned U.S. Pat. Application Ser. No. _____ (Attorney Docket No. M4065.0569), the disclosure of which is incorporated herein by reference.

[0049] Devices constructed according to the invention exhibit single polarity switching as illustrated in the graph of Fig. 5. Those having a silver-selenide layer disposed between two chalcogenide glass layers, in particular, are switchable between two resistance states using positive voltage pulses, and show improved memory retention and write/erase performance over conventional memory devices. These devices have also shown low resistance memory retention better than 1200 hours at room temperature.

[0050] Although the embodiments described above refer to the formation of only one resistance variable memory element 2, it must be understood that the invention contemplates the formation of any number of such resistance variable memory elements, which can be fabricated in a memory array and operated with memory element access circuits.

[0051] FIG. 6 illustrates a typical processor-based system 40 which includes a memory circuit 42, for example a programmable conductor RAM, which employs resistance variable memory elements fabricated in accordance with the invention. A processor system, such as a computer system, generally includes a central processing unit (CPU) 44, such as a microprocessor, a digital signal processor, or other programmable digital logic devices, which communicates with an input/output (I/O) device 46 over a bus 48. The memory 42 communicates with the system over bus 48 typically through a memory controller.

[0052] In the case of a computer system, the processor system may include peripheral devices such as a floppy disk drive 50 and a compact disc (CD) ROM drive 52, which also communicate with CPU 44 over the bus 48. Memory 42 is preferably constructed as an integrated circuit, which includes one or more resistance variable memory elements 2. If desired, the memory 42 may be combined with the processor, for example CPU 44, in a single integrated circuit.

[0053] The above description and drawings are only to be considered illustrative of exemplary embodiments which achieve the features and advantages of the invention. Modification and substitutions to specific process conditions and structures can be made without departing from the spirit and scope of the invention. Accordingly, the invention is not to be considered as being limited by the foregoing description and drawings, but is only limited by the scope of the appended claims.